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 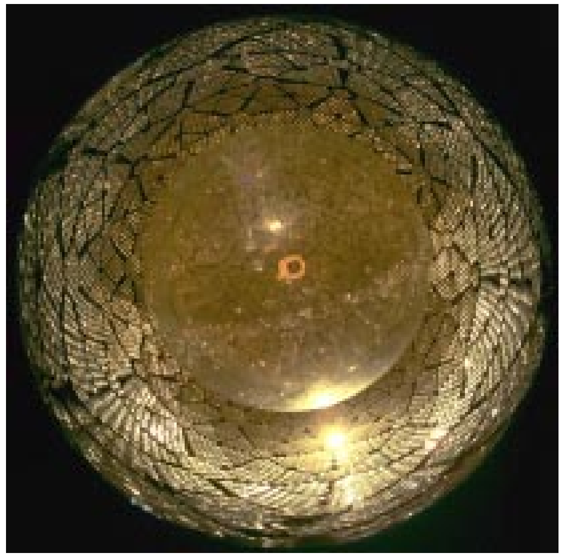

Institute for Nuclear and Particle Astrophysics

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Introduction

The areas of research at the Institute (INPA) are broad and have a strong interdisciplinary flavor, yet a common purpose connects them - to use the science and the technologies of nuclear physics and particle physics to address fundamental questions bearing on the nature of the universe: past, present, and future. Specific research topics include solar neutrinos, high energy neutrinos, detection of nearby and distant supernovae, weak interactions in atomic and nuclear processes, the cosmic microwave background radiation, direct detection of dark matter, cosmic rays and chronometers, the theory of pulsars and neutron stars, and geoastrophysics. Research and education are combined not only through the participation of students and postdoctoral researchers, but also at the high school level through summer programs for teachers and a major project, the Hands-On Universe, that brings on-line astronomical images to the classroom.

INPA is sponsored by the Nuclear Science Division and the Physics Division at LBNL. While participants in INPA are predominantly from these two Divisions, the Physics Department and the Space Sciences Laboratory at UC Berkeley are well represented. Indeed, the Institute benefits from the rich concentration of astrophysics in the greater Bay Area. A wide range of experimental facilities is used by INPA participants; at LBNL (the 88-Inch Cyclotron, Gammasphere, low-background counting facilities, Leuschner Observatory), in North America (Sudbury Neutrino Observatory, the Keck Telescopes, nuclear physics facilities at Argonne and Brookhaven national laboratories, university laboratories), throughout the world (Chile, Australia, Antarctica), and in space (HST, COBE).

This overview naturally focuses on research where Nuclear Science Division-associated researchers are heavily involved. A few highlights from other areas are mentioned, and the overview concludes with a brief description of INPA's institutional activities.

Neutrino Astrophysics

The Sudbury Neutrino Observatory (SNO), a 1,000-ton heavy-water Cerenkov detector under construction in a nickel mine in Canada, is nearing completion and will be filled with light and heavy water in the first half of 1998. This past year saw a number of significant milestones reached. The most significant for the LBNL members of the SNO collaboration occurred on January 23, 1998 when they installed the last of the ~9500 photomultiplier tubes in the geodesic support sphere (or PSUP). This represents the culmination of a design and construction effort that extended over nearly eight years. LBNL's contribution was completed on budget and within the time originally allocated to it. Another major milestone, which preceded this one, was the completion of the Acrylic Vessel, which will contain the heavy water. The views of the completed detector, from outside and inside, as shown in the wide-angle photographs above, are breath-taking. A particularly exciting moment occurred when the phomultiplier tubes saw "first light," which was provided by blue GaN light-emitting diodes that the group had installed on the PSUP. Attention at LBNL is now focused increasingly on calibration (^{16}N and ^{17}N sources, activated NaI and LED light sources), neutron detection (^{3}He neutron detectors), data acquisition (graphical interfaces and monitoring) and preparation for data analysis (Monte Carlo simulation and measurement of β and γ backgrounds, simulation of high-energy events).

When the detector is filled with water and ready to begin its shake-down period, the success of the contamination control efforts, which continue to involve the group, can be assessed. When SNO begins taking data, the years of planning and construction should bring their reward. By the year 2000, the neutral current to charged current ratio and the shape of the ^{8}B spectrum - two independent tests for neutrino oscillations - will have been measured and we should have a better perspective on the standard models of particle physics and of the sun.

The same properties of neutrinos that make them a valuable probe of the sun could also make them a unique window on the most energetic objects in the cosmos. Several INPA participants are members of the AMANDA collaboration, which is constructing a water Cherenkov detector in deep Antarctic ice to observe high energy neutrinos. It is in the planning and R&D toward the next generation neutrino observatory, however, that INPA is making a major contribution. This future detector will have dimensions on the order of a square or cubic kilometer, and therefore have the sensitivity to detect neutrinos from distant point sources, such as Active Galactic Nuclei.

Nuclear Astrophysics

Laboratory measurements of nuclear properties are essential in understanding the processes by which heavy nuclei are synthesized from primordial nuclei. Certain individual isotopes can take on key roles. ^{44}Ti is such an example; gamma rays from its decay are observable and can be used to determine the amount of ^{44}Ti produced in a supernova if the half life of this nucleus is known. Past measurements place this value in the range 39 to 67 years, which translates into a factor of six uncertainty for the remnant of a supernovae, CasA, that exploded 300 years ago. (Half lives in the range of tens of years are particularly difficult to measure). Measurements on ^{44}Ti produced at the 88-Inch Cyclotron and counted off-line have continued and yielded increasingly precise values. The results of two separate experiments are now 62 ± 5 and 61.5 ± 1.0. The small errors on the present values stem from preparing a ^{44}Ti source that contains admixtures of other isotopes with well-known half lives. The new value for the half live results in smaller amount of ^{44}Ti required to account for the supernovae remnants gamma-ray flux, which is easier to explain in the context of recent models of nucleo synthesis.

Knowing the half life of unstable (but long-lived) nuclei present in cosmic rays makes it possible to determine the residence time of these nuclei in our galaxy, i.e., they can serve as a cosmic chronometer. In this case, the half lives need to be of the order of 10^6 years. The decay rate of a nucleus in space (where it has no surrounding electrons to capture) can be much longer than when it is housed in an atom or ion on earth. Measurements of very weak decay branches are therefore necessary. ^{144}Pm and ^{54}Mn are two such cases; the latter nucleus is of particular interest because it has recently been possible to measure the relative abundance of the Mn isotopes in cosmic rays. Experiments have been made both at the 88-Inch Cyclotron using Gammasphere and at ANL with APEX. These experiments, by different groups using different experimental techniques, have yielded results in good agreement, with the cosmic ray half life of about 6 -8 x 10^5 years.

Since there is growing interest in nuclear astrophysics (and other areas of nuclear physics) in measuring cross sections on target nuclei that are off the line of stability, and hence radioactive, a series of thermal neutron capture measurements on the unstable isotopes ^{44}Ti, ^{68}Ge, and ^{148}Gd has been initiated.

The search for dark matter takes many forms. One form that has been suggested, heavy nuclei in the form of strange matter or nuclearites, i.e., aggregates of up, down, and strange quarks, has been searched for recently in an experiment at the 88-Inch Cyclotron. Samples of lunar soil, which might have a larger accumulation of nuclearites because of the lack of an atmosphere on the moon, were bombarded with 450 MeV Xe ions and the signature - a flood of gamma rays released by the deexcitation of the nuclearite - looked for with Gammasphere. Upper limits, lower by a factor of 3-4 orders of magnitude than previously determined, were set in this experiment.

Theory of Neutron Stars

A new method for detecting a change in composition or shape of a spinning neutron star, or pulsar, has been proposed. Such a change would be reflected in the time-structure of pulsar spindown. If the nuclear matter of a neutron star undergoes a phase transition to other baryonic species, its moment of inertia and, hence, rotational velocity will change. Such changes are expected because the changing angular velocity and centrifugal force will change the density profile as well, introducing thresholds at which new baryon species can be populated. The most striking signal of a phase transition could be the spontaneous spin up of a millisecond pulsar that should otherwise be spinning down due to angular momentum loss from radiation. Estimated to be on for about 100 million years, this should be an observable signal. In particular, the signal of a first-order phase transition is registered in the braking index of pulsars - a measurable quantity. It is estimated that the signal will be present in about ten of the presently known pulsars if the phase transition does take place.

Data for Nuclear Astrophysics

Nuclei heavier than lithium can only be made in stars, and in the later, rapid burning and explosive stages of stellar evolution. The prediction of the abundance of these nuclei is a triumph of nuclear astrophysics, and requires an amount of nuclear information on a similarly grand scale. INPA, the Isotopes Project, and UC Santa Cruz have assembled a number of the data-bases used in nucleosynthesis calculations and made them available to the community through our new Nuclear Astrophysics Data Home Page. The type and range of data available through this site has continued to grow as has the number of visitors to the web site.

Weak Interactions and Fundamental Measurements

The standard model of particle physics is the cornerstone for understanding the origin and development of the universe. Many of the key elements or parameters of the standard model are reflected in nuclear properties and measured in precision low-energy nuclear (or even atomic) experiments. We establish, test, and look for physics beyond the standard model in these nuclear physics experiments. Parity non-conservation, second class currents, time reversal invariance, the conserved vector current theory, double beta decay - these are some of the topics studied in the physics of weak interactions.

The trapping of radioactive neutral atoms with laser beams offers significant opportunities for increasing precision in tests of weak interaction theory. This is because the atoms are both confined in a vacuum and polarized by the trapping mechanism. During recent years, steady improvements in the laser trapping facility at the 88-Inch Cyclotron have led to the trapping of 5×10^4 ^{21}Na atoms ($t_{1/2}$ = 21s) and a precise measurement of the ground state hyperfine transition. The microwave spectroscopy techniques developed here will be used to characterize with high precision the nuclear polarization of an optically pumped group of atoms, which is necessary for the next steps, will be the installation of an in-vacuo beta detector in a secondary trap and a measurement of the beta-decay asymmetry.

The branching ratio for the super-allowed beta decay of ^{10}C(g.s. 0^+) to the first 0^+ state of ^{10}B is critical for the determination of the u-d element of the Cabbibo-Kobayashi-Maskawa mixing matrix. This matrix is assumed to be unitary in the standard model of electro-weak interactions. The present measurement of this branching ratio uses Gammasphere, a high-resolution gamma-ray detector array. A letter reporting the results of the first of two experiments has been submitted for publication. Analysis of the second run is in progress. Gammasphere is also ideal for the measurement of angular correlations, as in the case of the $\beta-\gamma$ directional correlation in the decay of ^{22}Na. This quantity enters into higher-order terms that test standard model predictions and can be used to search for second class currents. Analysis of the 4×10^9 events collected in three runs has been completed and produced a new result with a factor of two smaller uncertainty than previous measurements.

The detailed shape of the energy spectrum in beta decay is related in the conserved vector current (CVC) theory to the strength of an associated electromagnetic transition. ^{14}C and ^{14}O are two cases for testing CVC. Measurements on the former nucleus have been completed (at ANL), and the shape factor in ^{14}C appears to be in good agreement with the value predicted by CVC. ^{14}O will be studied at the 88-Inch Cyclotron using a new, high-efficiency Cusp ion source for the production of the ^{14}O ($t_{1/2}$ = 71 s) radioactive source. The multi-wire proportional chamber has been completed and the high efficiency multicusp ion source, necessary for the production of a radioactive "beam" of ^{14}O, will be installed in the spring of 1998.

The breaking of CP symmetry explains the predominance of matter over anti-matter in the universe. The most fundamental theorem in physics, "CPT=1" implies that Time Reversal Invariance (TRI) must also be broken at some level. Searches for TRI-violating effects are therefore important for our understanding of how the universe evolved immediately after the Big Bang. Two searches are in progress. The first, called "emiT", is a study of the directional correlations in the beta decay of spin-polarized neutrons. This experiment, a collaboration of several institutions, has been several years in preparation, and has just completed data taking in its first experiment with the cold neutron source at NIST. The other experiment uses low temperatures to align nuclei of ^{56}Co and observes the directional correlation of the nuclear spin, the emitted positron, and a subsequent gamma ray. This experiment is scheduled to have results later this year.

The weak interaction responsible for nuclear beta decay (W-exchange) can induce a small Parity Non Conserving component in electromagnetic transitions in atomic systems through the weak neutral current (Z-exchange). The latter thus complements the study of nuclear beta decay. Atomic PNC experiments are in progress on a range of stable isotopes of Yb and may yield information on the weak interaction independent of atomic structure.

The beta decay of ^{8}B is under renewed study because of its importance to the measurement of the ^{8}B solar neutrino spectrum in SNO and SuperKamiokande. The prediction of the neutrino spectrum is complicated by the presence of unbound states in the ^{8}Be residual nucleus, making desirable an experimental determination of the spectral shape from the energies of the two alpha particles. The experiment will be done at ANL using the ATLAS spectrograph and secondary beam of ^{8}B nuclei, which will be implanted into a silicon detector.

Low Background Counting

The Low Background Counting Facilities used in the study of double β decay have also been instrumental in a wide variety of experiments and in support activities for other institutions. The other types of work (done at the facilities at Berkeley and at Oroville) include low-activity materials certification, cosmic ray activation, neutron activation analysis, and environmental health and safety activities.

Past and Future

We note here two projects that address the early history and the ultimate fate of the universe and which are based in the Physics Division. The cosmic microwave background radiation observed today reflects the state of the universe about $3x10^{5}$ years after the Big Bang, at the time radiation and matter decoupled. The next generation of satellites, to follow COBE in the study of anisotropies in the CMBR, are being planned.

More recent history (the last few million years) is being studied by the geoastrophysics group, which has reexamined the cyclical nature of the ice ages, and offered a new hypothesis on the origin of the 100,000 year periodicity. The new suggestion, that changing inclination of the earth's orbit to those of the other planets moves the earth into and out of regions of interplanetary dust, is under active discussion among climatoligists.

The future fate of the universe depends on its matter density, which is expressed as a ratio to a critical density at which the expansion rate of the universe slows to zero at infinite time. The supernova cosmology project searches for (and regularly discovers!) type 1A supernovae at very large distances. In essence, the luminosity of a type 1A supernova is a constant or "standard candle," which gives its distance, and the red shift of its host galaxy gives its velocity. Thus, the Hubble diagram can be extended to very large distances (or far back in time). Deviations from a linear dependence of recessional velocity on distance have indicated that W_m (the ratio of the mass density of the universe to the critical value) is substantially less than 1 and, equally momentous, that the cosmological constant, W_l , originally proposed by Einstein and later retracted, is likely finite. The small value of W_m and finite W_l imply that the universe will expand forever.

Institutional Activities

The purpose of the Institute is to further interdisciplinary work in Nuclear and Particle Astrophysics at LBNL by:

- promoting interaction and communication among its members
- sharing of intellectual, technical, and administrative resources
- planning of new research proposals and development of detector systems
- developing innovative educational outreach programs
- establishing seminar, postdoctoral, and visitor programs
- sponsoring of workshops

The list of active participants has grown to approximately 80, while the number of people receiving e-mail announcements of the weekly Journal Club is ~200. Attendance at the Journal Club is typically 30-40 people. The daily tea has become an established feature of INPA life and attracts usually 15-20 people for conversation and lively argument. The Common Room is heavily used for regularly scheduled group meetings and ad-hoc get-togethers. The list of Journal Club speakers is contained elsewhere in this Annual Report.

New initiatives in which INPA plays an important role are the R&D for the next generation of high energy neutrino detector and the development of a Nuclear Astrophysics Data Center.

Visitors are invited to spend time from a week to several months at the Institute. In previous years visitors have included Lawrence Krauss (Case Western Reserve University), Guy Savard (Chalk River Nuclear Laboratories), Richard Kron (University of Chicago and FNAL), David Branch (University of Oklahoma), Angela Olinto (University of Chicago), Joshua Frieman (University of Chicago and FNAL), Baha Balantekin (University of Wisconsin at Madison), and Michael Turner (University of Chicago and FNAL). This last year, Michael Ramsey-Musolf, George Fuller, Wick Haxton, and Baha Balantekin visited.

Workshops and Meetings Sponsored by INPA

General Meeting of the UC System-wide "Institute for Nuclear and Particle Astrophysics and Cosmology" (INPAC), May, 1997

Additional information on the Institute and its activities can be found on the World Wide Web under the URL http://www-inpa.lbl.gov/.

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